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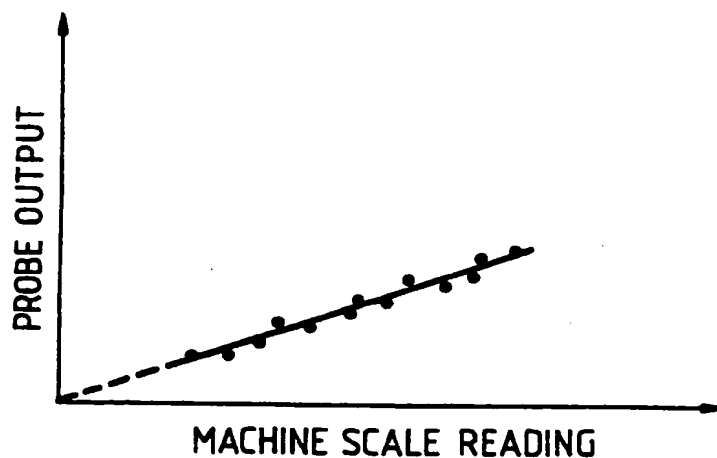
(57) Abstract

A method of measuring the position of a workpiece surface is disclosed which utilises an analogue probe which produces at least one output indicative of the amount of stylus deflection. The probe is driven by a machine towards the surface, and when contact is made the initial deflection signal triggers the machine controller to read simultaneously the outputs of the machine scales and the probe output at the time of the signal and at several further instants over a short time period before the machine is stopped. A computer then plots the relationship between the probe readings and the machine scale readings and extrapolates it back to the point at which the probe stylus deflection was zero. This gives an indication of the position of the stylus at the actual instant of contact. A further benefit is that, because the probe stylus remains in contact with the workpiece surface for a short time while readings are being taken, any inaccuracies introduced because of machine vibration can be averaged and thus reduced by plotting a best fit line through the recorded points.

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A METHOD OF MEASURING WORKPIECES USING A SURFACE
CONTACTING MEASURING PROBE

The present invention relates to measurement of workpieces.

5

Analogue probes are known in which the deflection of a
probe stylus when acted upon by a force is directly
measured by measuring devices within the probe.

10   It is known, for example, from UK Patent No 1,573,447, to
have an analogue probe in which the stylus deflection in
each of three orthogonal axes is measured separately and
individual outputs of the deflection in each axis are
provided separately. It is also known, for example, from
15   UK Patent No. 1,237,813 to provide only a single output of
stylus deflection from a single one dimensional measurement
transducer which is arranged to be moved by both an axial
movement of the stylus in its measuring direction, and a
tilting movement of the stylus about any axis in a plane
20   transverse to the measuring direction.

In a probe of the latter kind, while the movement of the
transducer within the probe bears a one to one relationship
with the movement of the stylus in the measuring direction
25   of the transducer, this is not so with movement in any
other direction. Hence it is not possible with such probes
to determine exactly the x, y and z coordinates of the
displacement of the stylus tip.

30   According to the present invention there is provided a
method of measuring a workpiece using a machine on which a
measuring probe is mounted for movement into different
positions to enable the probe to contact the workpiece,
said machine having at least one measuring device for
35   providing an output indicative of the position of the probe
relative to a datum position, the probe having a
deflectable workpiece-contacting stylus and at least one
measuring device for providing an output indicative of the

amount of deflection of the stylus from a rest position,
the method comprising the steps of:

moving the probe to bring the stylus into contact with
5   the surface of a workpiece to be measured and continuing
said movement for a further limited distance after initial
contact has been made between the stylus and the workpiece,
simultaneously recording the outputs of the measuring
devices of the machine and of the probe at a plurality of
10   instants during said further movement,
computing by extrapolation from said recorded outputs
the values of the outputs of the measuring device or
devices of the machine which were existing at the instant
that the probe stylus was last in a state of zero
15   deflection, and
providing said value or values as the output of the
machine.

By this means the position of the probe stylus at the
20   instant of first contact between the stylus and the
workpiece surface can be determined accurately regardless
of the direction of the relative movement between the
stylus and the workpiece.

25   In a preferred embodiment of the invention the output of
the probe measuring device is arranged to have a linear
relationship with deflection of the stylus and is set to be
zero in the undeflected condition of the stylus. Under
these circumstances the computing step includes the steps
30   of computing the best fit of a straight line through the
recorded points and extrapolating this line back to the
point at which the probe output would have been zero.

This additional step enables the following further
35   significant benefit to be derived from the invention.

When measuring workpieces on machines, there may be
vibrations affecting the machine which result in errors

being produced in the probe readings at the precise moment
of contact. Using the present method, the probe stylus
remains in contact with the workpiece for a significant
period of time while the probe and machine outputs are

5   being recorded. By calculating the best fit line through
the recorded outputs the errors due to vibration will be
averaged and the accuracy of the extrapolated point will be
enhanced. This aspect of the invention can bring improved
accuracy by applying the method of the invention to a probe

10   in which the movements of the stylus in all three axes is
individually measured by separate transducers.

Where the probe is being moved along only one axis for
taking a measurement, clearly only the one measuring device

15   of the machine will be recording the movement and only a
single straight line will be calculated. However, where
the machine is capable of moving the probe in three axes
and the probe is being moved along more than one axis
simultaneously, the calculating step will either be done

20   for each axis individually, or all moving axes
simultaneously to produce a line in three dimensions.

The machine with which the method may be carried out may be
a co-ordinate measuring machine or machine tool.

25
The invention will now be more particularly described, by
way of example only, with reference to the accompanying
drawings in which:

30   Fig 1 is a diagrammatic representation of a machine with
which the invention is used.

Fig 2 is a diagrammatic representation of the probe on the
machine of Fig 1.

35
Fig 3 is a graphical representation of the calculation
performed by the computer of the machine of Fig 1.

Fig 4 is a diagrammatic layout of the apparatus required to perform the calculations in accordance with the present invention.

5   Referring now to the drawings, there is shown in Fig 1 a basic co-ordinate measuring machine which is well-known in the art.   The machine is a gantry type machine in which two side pillars 1 and 2 are movable along a base 3 in a first direction x, their movement being measured by a suitable

10 scale 4 and scale reader 4A.   The pillars support a bridge 5 which extends in a second direction y, at right angles to the x direction and on which a carriage 6 is mounted for movement in the y direction.   In turn the carriage supports a spindle 7 which extends in a third direction z at right

15 angles to both of the x and y directions.   Further scales and scale readers (not shown) measure the movement of the carriage in the y direction and of the spindle in the z direction.   The scales and scale readers constitute the measuring devices of the machine.

20
Thus it can be seen that a probe attached to the end of the spindle can be positioned anywhere within the working volume of the machine to measure a workpiece mounted on the base.   This may be accomplished manually, or by a machine

25 controller under the guidance of a computer 9 connected to the machine by a cable 10.

The probe shown in Fig 2 has a well known construction, for example as shown in UK Patent Specification No. 2,094,478A

30 and is not therefore described in detail.   Basically it includes a workpiece-contacting stylus 10 which is carried by a plate 12 having a plane undersurface 13 supported on a an annular knife-edge 15, and urged into contact with the knife-edge by a spring 16.   The stylus has a workpiece-

35 contacting ball 18 at its end.   Thus it can be seen that the stylus can be displaced in the z direction (vertically in the drawing) and can be tilted about the knife-edge when acted upon by forces in any directions in x y plane.   The

probe has a longitudinal axis 11 with which the
longitudinal axis 10A of the stylus is aligned.

A single probe measuring device 20 is provided which is
5   constrained for uni-directional movement in the z
     direction. The device provides an output 21 indicative of
     the movement of the plate in the z direction when a force
     acts on the stylus ball in any direction. Various forms of
     measuring device may be used for example, inductive or
10   capacitive transducers, or piezo resistive or other forms
     of strain gauges, but a preferred form is a conventional
     LVDT.

     Clearly the output of the transducer will be less for a
15   tilting movement of the plate, due to a given deflection of
     the end of the stylus caused by a force in the x, y plane,
     than it would be for the same deflection of the stylus in
     the z direction.

20   Thus it is not possible from the single transducer output
     to determine the precise deflection of the stylus ball in
     the x, y and z direction after a contact has been made with
     the surface of the workpiece. The use of the analogue
     output of such probes has therefore in the past been
25   limited to using a threshold level of output to indicate
     that a contact has been made with the workpiece, and to
     cause a signal to be sent to the machine to output the
     instantaneous readings of the scales and stop further
     movement of the machine. The position of the stylus ball
30   in space was then determined by the computer from the
     instantaneous machine scale readings and from a previous
     calibration of the probe relating to stylus pre-travel.

     In order to be able to determine the precise position of
35   the stylus ball in the working volume of the machine when
     it contacts the surface of the workpiece the following
     method is adopted.

The output of the probe measuring device (LVDT) is set to a
value, which may conveniently be zero, which represents the
position of the stylus ball relative to the fixed probe
axis in the rest position of the stylus i.e. the position
5   it occupies when no external force acts on the stylus ball.
The probe is then driven by the machine controller towards
the workpiece.

As soon as the stylus ball is deflected by contact with the
10 workpiece the output of the LVDT changes and this causes a
signal to be sent to the machine controller (in known
manner) to commence reading the machine scales and to
output the values as an output 22 to the computer. A
further limited amount of travel of the machine is allowed
15 by the computer and during this time the outputs of all of
the machine scales and the probe LVDT are recorded
simultaneously at intervals and stored. When sufficient
readings have been taken the controller stops the machine
and the computer calculates from the stored readings a
20 notional straight line through the readings and
extrapolates back to find the reading of each of the
machine scales which would have existed at the very instant
the stylus ball contacted the workpiece. That is, the
reading of each of the machine scales at the point when the
25 output of the probe LVDT was last at the level equating to
the rest position of the probe stylus. The calculated
scale readings at this rest position of the stylus are
provided by the computer as the output of the machine.

30 Thus by using the method of the present invention it is
possible to determine precisely the first instant of
contact between the stylus and the workpiece without having
to make allowances for the different relationships between
the LVDT output and the stylus deflection in all
35 directions. In fact it is not necessary even to know what
the relationships are.

Where the probe is of the type having only a single output
transducer, problems may arise when the stylus approaches
an inclined surface, in that the stylus may slip to one
side when contact is made with the surface. To avoid this
5   problem the machine should be programmed to ensure that the
stylus approaches the surface in a direction which is
normal, or substantially normal, thereto within the angle
of friction.

10   Fig 3 shows by a graphical representation the calculations
which are made by the machine's computer. The vertical
axis shown represents the output 21 of the probe LVDT and
the horizontal axis represents the machine scale output 22
on one axis. It can be seen that as the machine continues
15   its limited movement after the first contact has been made
between the probe stylus and the workpiece, the probe LVDT
output increases. Depending on the speed at which the
readings of the machine scales and probe outputs can be
read and recorded, readings are taken over a time period
20   from a fraction of a millisecond to a few milliseconds
before the controller stops the machine.

The probe LVDT is designed to have a linear displacement
versus output signal characteristic so that it can be
25   easily extrapolated backwards to determine what the machine
scale reading was when the level of the output of the probe
LVDT was last at the level set for the rest position (in
this example a zero level). However, this is not an
essential requirement, and measuring devices with non-
30   linear characteristics may be used provided that a
calibration of the characteristic is pre-programmed into
the computer.

Where the machine is moving the probe in more than one axis
35   simultaneously, the machine computer has to be programmed
to perform the calculation for all three machine axes to
determine the x, y and z coordinates of the point of first
contact between the stylus and workpiece.

If the probe is being used on a coordinate measuring
machine in a still environment there will be little or no
machine vibrations to upset the straight line plot of the
probe LVDT versus machine scale readings. However, where
5   the probe is used in a more hostile environment, for
example, on a machine tool, the vibrations of the probe and
workpiece will provide errors in the readings recorded, to
the extent that they will not lie on an obvious line. In
these circumstances the computer is programmed to calculate
10   the best fit of a straight line through the points on the
notional graph, and then to extrapolate that line back to
find the machine scale readings at the probe output
representative of zero deflection of the stylus. Provided
the time interval over which readings are taken is greater
15   than one full vibration cycle, the errors introduced by the
vibration will be averaged and hence significantly reduced.

Within the computer the elements of software and hardware
required for performing the calculations are generally
20   known and are illustrated in Fig 4. The first deflection
reading from the probe LVDT is passed to a clock 25 which
times the sequence of simultaneous readings of the probe
LVDT outputs 21 and machine scale outputs 22. These
readings are passed to a memory store 26. When all
25   required readings have been taken the clock stops and the
machine movement is terminated. The stored readings are
passed to a function generator 27 which produces a best fit
straight line through the readings by the least squares
method, and then an extrapolator 28 extrapolates the line
30   back to the defined rest position output (zero) and outputs
the machine scale readings corresponding to this value.

The function generator may calculate the best fit straight
line separately for each axis, or calculate the best fit of
35   the vector in three dimensions before extrapolating back to
the zero output point.

9

The invention allows a very simple, single transducer, analogue probe to be used to enable the machine to produce a signal at the precise mechanical zero of the probe which relates to the instant of contact of the probe stylus with

5   the workpiece. Thus the probe effectively behaves as if it was operating in the touch trigger mode of operation, but with much greater accuracy than in the past using the threshold trigger method.

10   However, the benefits of the invention may be obtained with different forms of analogue probe. For example, a probe may be used which produces three independent outputs when the stylus is deflected, one for each of the x,y and z axes. With such a probe, the outputs of all three axes may

15   be plotted separately against the outputs of the scale readers on the corresponding axes.

Another form of analogue probe which may be used, in accordance with the method of the present invention, is a

20   probe of the type described in European Patent Specification No. 87105395.5. Although described as producing a single trigger signal after a threshold level of strain has been recorded from three strain gauges in the probe, the circuit could be modified to raise the threshold

25   level, and to record the strain readings of the strain gauges individually, or in combination, to respectively provide three graphs, or a single combined graph, from which an extrapolated zero strain value can be derived as explained above.

30

Other benefits may be derived from the timed readings taken of the probe and machine outputs. For example, by considering two readings a known time interval apart, both the direction and speed of travel of the probe at the

35   instant of contact may be determined.

In a modification to the above-described method an analogue probe of any of the above-described types may be used to

average out the vibrations of a workpiece using the
following method.

The probe is moved to contact the vibrating surface of a
5   workpiece and when contact is established, as seen by a
change in the output, the machine movement is continued
until the probe output or outputs indicate that the probe
stylus has deflected up to say, half of its deflection
range, at which point the machine is stopped. The reading
10   of the probe output or outputs however, continue to be
monitored for a few milliseconds to establish the full
range of the vibration of the workpiece. The readings are
then averaged by the machine computer. From the average of
say 50 readings, in combination with machine scale readings
15   at the instant of contact, the actual position of the
surface of the workpiece can be determined with a greater
degree of certainty than if a single reading of the machine
outputs is taken when the probe indicates contact with the
workpiece.

20

This method is of value in a machine tool having two
operational spindles, enabling one workpiece to be measured
accurately while another is being machined. The method is
also of particular advantage for increasing the versatility
25   of an analogue probe which produces only a single output
for deflection of the stylus in any direction, various
types of which are described above.

The probe may be positioned against the workpiece surface
30   in a part-deflected position by using the machine servos
controlled from the probe outputs, or where the position of
the surfaces of the workpiece to be measured have been pre-
programmed into the machine, and the probe stylus has a
large deflection range, the machine can simply be driven to
35   its pre-programmed location.

CLAIMS

1.   A method of measuring a workpiece using a machine on
which a measuring probe is mounted for movement into
5   different positions to enable the probe to contact the
workpiece, said machine having at least one measuring
device for providing an output indicative of the position
of the probe relative to a datum position, the probe having
a deflectable workpiece-contacting stylus and at least one
10   measuring device for providing an output indicative of the
amount of deflection of the stylus from a rest position,
the method comprising the steps of:

     moving the probe to bring the stylus into contact with
15   the surface of a workpiece to be measured and continuing
said movement for a further limited distance after initial
contact has been made between the stylus and the workpiece,
     simultaneously recording the outputs of the measuring
devices of the machine and of the probe at a plurality of
20   instants during said further movement,
     computing by extrapolation from said recorded outputs
the values of the outputs of the measuring device or
devices of the machine which were existing at the instant
that the probe stylus was last in a state of zero
25   deflection, and
     providing said value or values as the output of the
machine.

2.   A method as claimed in claim 1 and comprising the
30   further step of moving the probe so that the stylus
approaches the surface of the workpiece in a direction
which is substantially normal thereto.

3.   A method as claimed in claim 1 and wherein the
35   computing step comprises the step of computing the best fit
line through the recorded outputs.

4.   A method as claimed in claim 1 and wherein the probe
produces at least one output signal which varies linearly
with the deflection of the stylus, and the computing step
comprises the step of computing the best fit straight line
5   through the recorded outputs.

5.   A method as claimed in claim 4 and wherein the
computing step includes the steps of computing the position
of the probe at the condition of zero stylus deflection in
10   each of the three machine axes independently.

6.   A method as claimed in claim 3 and wherein the
computing step includes the steps of computing the single
three dimensional vector of the stylus deflection by
15   combining the recorded outputs of the measuring devices of
the machine and the probe in three orthogonal axes, and
extrapolating the single vector back to obtain the position
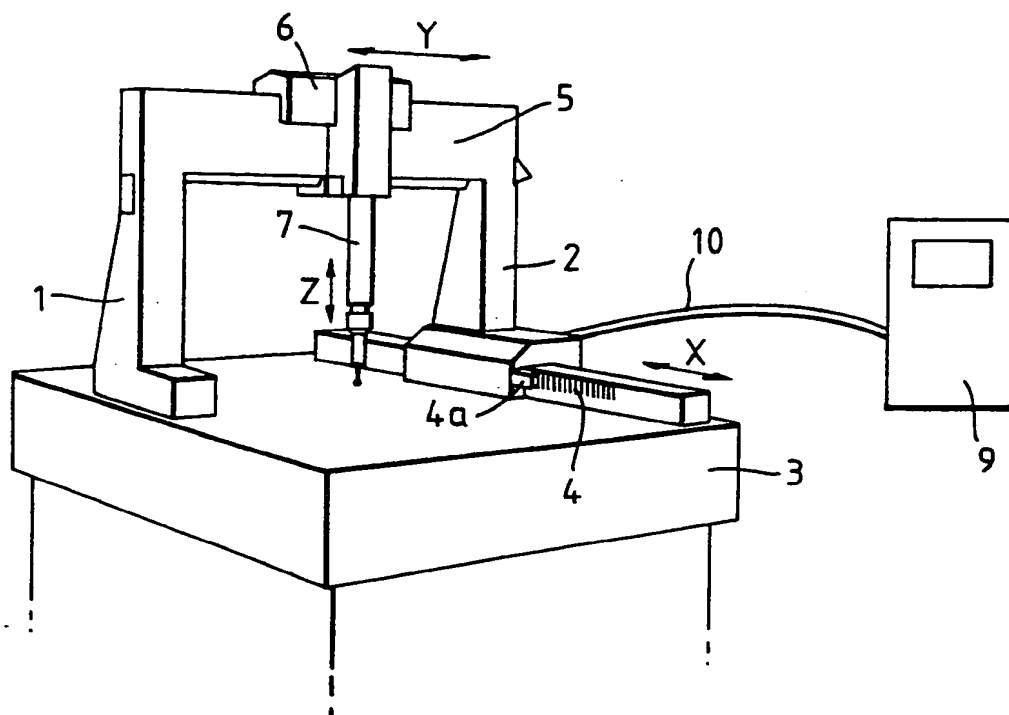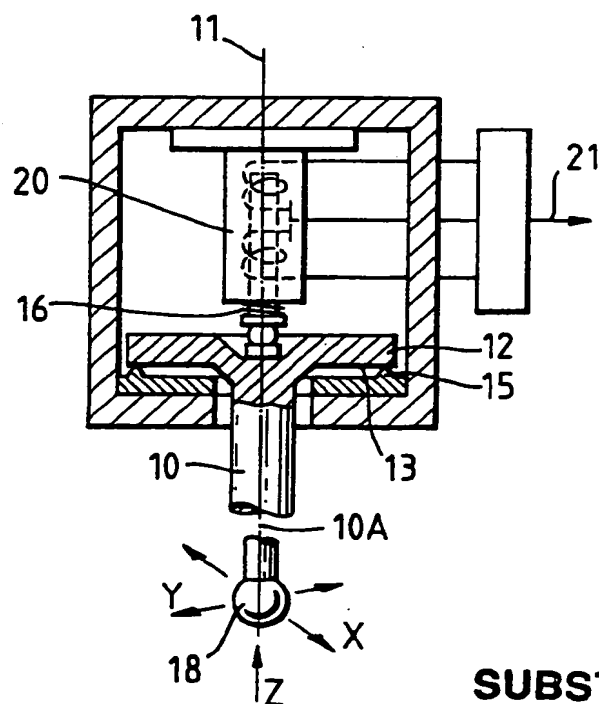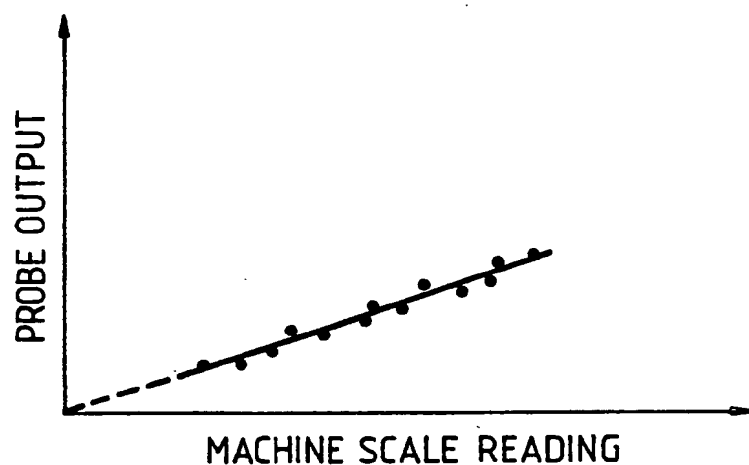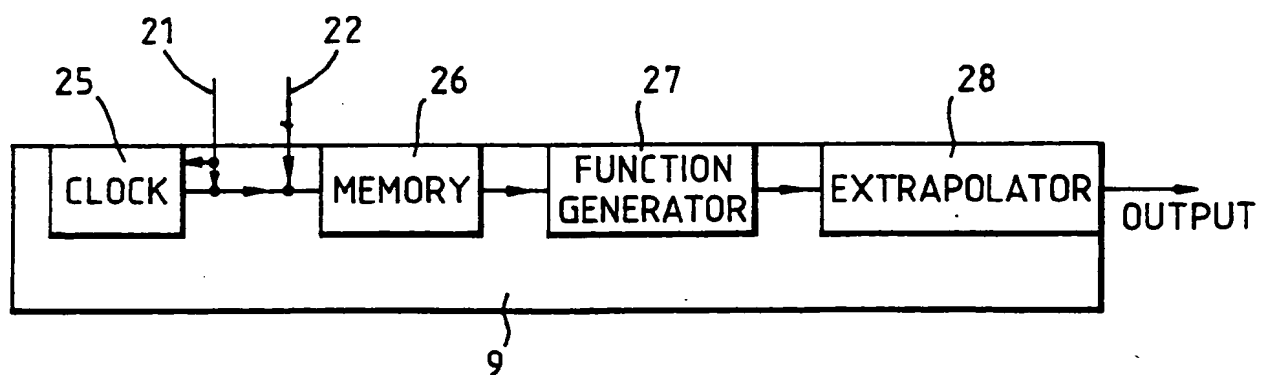of the probe at the condition of zero stylus deflection.

Fig. 1.

Fig. 2.

SUBSTITUTE SHEET
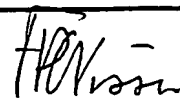
Fig.3.

MACHINE SCALE READING

Fig.4.

I. CLASSIFICATION OF SUBJECT MATTER   (if several classification symbols apply, indicate all)[6]

According to International Patent Classification (IPC) or to both National Classification and IPC

Int.Cl. 5 G01B21/04;   G01B7/00;   G05B19/18

II. FIELDS SEARCHED

Minimum Documentation Searched[7]	
Classification System	Classification Symbols
Int.Cl. 5	G01B ; G05B

Documentation Searched other than Minimum Documentation
to the Extent that such Documents are Included in the Fields Searched[8]

III. DOCUMENTS CONSIDERED TO BE RELEVANT[9]		
Category[°]	Citation of Document,[11] with indication, where appropriate, of the relevant passages[12]	Relevant to Claim No.[13]
A	WO,A,8 903 509 (BROWN & SHARPE MANUFACTURING CO.) 20 April 1989 see introduction; see page 8, paragraph 2 - page 23, paragraph 2; figures 1-5D ---	1-6
A	US,A,4 118 871 (KEARNEY & TRECKER CORP.) 10 October 1978 see the whole document see figure 1 ---	1
A	DE,A,3 336 854 (DR. JOHANNES HEIDENHAIN GMBH) 2 May 1985 see page 6, paragraph 2 - page 9, paragraph 3; figures 1-3 ---	1

° Special categories of cited documents :[10]

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier document but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art.

"&" document member of the same patent family

IV. CERTIFICATION	
Date of the Actual Completion of the International Search	Date of Mailing of this International Search Report
13 AUGUST 1992	27. 08. 92
International Searching Authority	Signature of Authorized Officer
EUROPEAN PATENT OFFICE	VISSER F.P.C.

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ANNEX TO THE INTERNATIONAL SEARCH REPORT
ON INTERNATIONAL PATENT APPLICATION NO.

GB 9200906
SA 59449

This annex lists the patent family members relating to the patent documents cited in the above-mentioned international search report.
The members are as contained in the European Patent Office EDP file on
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Patent document cited in search report	Publication date	Patent family member(s)		Publication date
WO-A-8903509	20-04-89	US-A-	4866643	12-09-89
US-A-4118871	10-10-78	None		
DE-A-3336854	02-05-85	DE-A-	3470601	26-05-88
		EP-A,B	0147529	10-07-85
		JP-A-	60097207	31-05-85
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